Injuries From Roadside Improvised Explosive Devices

Arul Ramasamy, MA, MRCS, MFSEM, RAMC, Stuart E. Harrisson, MRCS, RAMC, Jon C. Clasper, DPhil, DM, FRCS, RAMC, and Michael P.M. Stewart, QHS, FRCS, FRCS (Tr+Orth), L/RAMC

Background: After the invasion of Iraq in April 2003, coalition forces have remained in the country in a bid to maintain stability and support the local security forces. The improvised explosive device (IED) has been widely used by the insurgents and is the leading cause of death and injury among Coalition troops in the region.

Method: From January 2006, data were prospectively collected on 100 consecutive casualties who were either injured or killed in hostile action. Mechanism of injury, new Injury Severity Score (NISS), *The International Classification of Disease—9th edition* diagnosis, anatomic pattern of wounding, and operative management were recorded in a trauma registry. The weapon incident reports were analyzed to ascertain the type of IED employed.

Results: Of the 100 casualties injured in hostile action, 53 casualties were injured by IEDs in 23 incidents (mean 2.3 casualties per incident). Twenty-one of 23 (91.3%) of the IEDs employed were explosive formed projectile (EFP) type. Twelve casualties (22.6%) were either killed or died of wounds. Median NISS score of survivors was 3 (range, 1–50). All fatalities sustained unsurvivable injuries with a NISS score of 75. Primary blast injuries were seen in only 2 (3.8%) and thermal injuries in 8 casualties (15.1%). Twenty (48.7%) of survivors underwent surgery by British surgeons in the field hospital. At 18 months follow, all but one of the United Kingdom Service personnel had returned to military employment.

Conclusions: The injury profile seen with EFP-IEDs does not follow the traditional pattern of injuries seen with conventional high explosives. Primary blast injuries were uncommon despite all casualties being in close proximity to the explosion. When the EFP-IED is detonated, the EFP produced results in catastrophic injuries to casualties caught in its path, but causes relatively minor injuries to personnel sited adjacent to its trajectory. Improvements in vehicle protection may prevent the EFP from entering the passenger compartments and thereby reduce fatalities.

Key Words: War injuries, Iraq, Improvised explosive device, shaped charge explosive, Blast injuries, Field hospital, Explosive formed projectile, Terrorism.

J Trauma. 2008;65:910–914.

After the invasion of Iraq in April 2003, British and coalition forces have remained in South Eastern Iraq as part of a UN mandated force in a bid to aid stability and to support the Iraqi security forces. Despite the end of the war-fighting phase, casualties have continued to be inflicted on coalition troops deployed to the region. Previous work published on casualties of hostile action treated in Coalition Field Hospitals during the first Gulf War in 1991,[1] and in the war fighting phase of this conflict in 2003[2] have reported a pattern of injury in keeping with a perceived conventional battlefield.

However, this insurgency has been characterized by the use of the improvised explosive device (IED), with over 10,000 such attacks reported in Iraq during 2005.[3] The US Department of Defense defines them as devices placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic or incendiary chemicals, designed to destroy, disfigure, distract or harass and often incorporate military stores.[4]

Submitted for publication March 25, 2008.

Accepted for publication June 24, 2008.

From the Academic Department of Military Surgery and Trauma, ICT Centre, Birmingham, United Kingdom.

Address for reprints: Arul Ramasamy, MA, MRCS, MFSEM, ICT Centre, Birmingham Research Park, Birmingham B15 2SQ, United Kingdom; email: arul49@doctors.org.uk.

DOI: 10.1097/TA.0b013e3181848cf6

In Iraq, they have been the leading cause of death among coalition troops, and have resulted in 1,690 fatalities from June 2003 to January 2008.[5] Data from the US Joint Theater Trauma Registry (JTTR) have shown that explosions were the causative mechanism of injury in 79% of troops wounded in action, and IEDs accounted for 38% of all combat injuries, and 32% of combat fatalities.[6–8]

Injuries from explosions are classified into four categories: primary, secondary, tertiary and quartenary blast injuries. Primary blast injuries are caused by the sudden increase in air pressure after an explosion. Air-containing organs, such as the middle ear, lungs, and gastrointestinal tract are susceptible to the effects of the blast wave. Eardrums may rupture at pressures of 2 psi, whereas pulmonary effects are seen at 70 psi. Exposure to pressures above 80 psi is associated in death for more than 50% of cases.[9] Tissue susceptibility to the effects of primary blast is inversely related to the third power of a victim's distance from the explosion. Consequently, the presence of severe pulmonary damage is evidence of the proximity of the victim to the explosion.

Secondary blast injuries occur when bomb fragments or nearby debris are energized by the explosion and cause injury by penetrating trauma. Tertiary blast injury is caused when the casualty is thrown by the explosion and collides with nearby objects.[10] Quartenary blast injury is related to the thermal effects of the explosion.

The effects of these different blast mechanisms are dependent on a number of factors. Leibovici compared the effects of explosions occurring in open spaces compared with enclosed spaces. He found that explosions in confined spaces were associated with a higher incidence of primary blast injury, increased severity, increased mortality, and severity of burns compared with explosions in open air.[11] These findings have been corroborated by meta-analysis of a number of terrorist bombings over the past 40 years.[12]

A recent case-series from a United States shock trauma platoon in Iraq showed that of the 18 casualties injured in close proximity IED explosions, 50% died and there was an increase in the injury severity of survivors from incidents where there was an associated fatality.[13] Given that IEDs in Iraq are often camouflaged and laid under the road or by the roadside, targeted vehicles are in close proximity to the device when it is detonated. Although, these events are open-air explosions, where the blast wave overpressure is dissipated in a very short distance, we hypothesized that the very close proximity of the device to the vehicle would still result in a significant proportion of primary blast injury effects.

The aim of this study was to document the incidence of IED injuries, as well as report the pattern of injury and cause of death of coalition troops injured in IED attacks presenting to the British military field hospital in Iraq.

METHOD

The British Military Field Hospital Shaibah is the sole military hospital supporting Coalition forces in South Eastern Iraq, treating both Coalition and Iraqi civilian casualties. In addition, it provides a medical and surgical facility for the United Kingdom service personnel deployed in the area.

From January 2006, two surgical residents deployed to the field hospital as general duties medical officers, prospectively collected data on 100 consecutive casualties of hostile action. Casualties killed in action (KIA) were included in the study. KIA was defined as those fatalities who had died before arrival at a medical treatment facility, and died of wounds were those who died after arrival at a medical treatment facility.[14] For each patient, demographic information and anatomic pattern of wounding were collated in a trauma registry. In addition, the reports from the ordnance experts were used to confirm the type of weapon used in the IED attacks. The IEDs were classified as either (i) explosive formed projectile (EFP-IED), (ii) conventional explosive devices formed from munitions or (iii) suicide or vehicle borne devices.

An anatomically based new Injury Severity Score (NISS)[15] was used to calculate the severity of the injuries. The system is built on the Abbreviated Injury Score (AIS) and sums the severity score of the three most severe injuries irrespective of the body region. *The International Classification of Disease—9th edition*[16] was used to categorize the injuries encountered. For those service personnel killed in hostile action, post-mortems were carried out in the United Kingdom by Home Office forensic pathologists and the reports were obtained to ascertain the severity of injury and categorize the injuries.

RESULTS

Between January and October 2006, there were 100 casualties from hostile action who were either KIA or presented to British Military Field Hospital Shaibah for treatment. The injury mechanism of all casualties is presented in Table 1. Fifty-three (53%) were injured or killed by an IED, and these patients form the cohort of this study. Forty-seven were coalition forces (39 UK, 3 US, 5 Danish), five were foreign civilians, and one was a local civilian.

All IED incidents during the study period were roadside devices directed against coalition force vehicles. These casualties were injured in 23 incidents (mean 2.3 casualties per incident; range, 1–5). Twenty-one of the incidents were EFP-IED type (91.3%), one improvised mortar round, and one vehicle borne suicide IED. There were 12 (22.6%) deaths from IEDs; 11 were KIA and 1 subsequently died of wounds in hospital. All deaths occurred with EFP-IEDs. All except one casualty were wearing combat body armour and helmets at the time of injury.

The anatomic pattern of wounding is represented in Table 2. Extremity injuries were common in both the survivor and fatalities group and present in 86.7% of all casualties. Survivors often presented with multiple injuries with a mean 2.61 body areas affected (range, 1–6). Injuries to the torso in

Table 1 Mechanism of Injury of All Wounded and Killed Combatants

Mechanism of Injury	Killed	Wounded	Percent
GSW	3	19	22
Explosion	18	60	78
IED	12	41	53
Mortar	1	17	18
RPG	0	2	2
Missile	5	0	5
Total	21	79	100

Table 2 Anatomical Pattern of Wounding

Anatomical Locations	IED Survivors	IED Fatalities
Lower extremities	37 (90)	6 (50)
Upper extremities	37 (90)	9 (75)
Face	13 (32)	6 (50)
Neck	8 (20)	7 (58)
Head	6 (17)	7 (58)
Abdomen	0 (0)	5 (42)
Pelvis	0 (0)	7 (58)
Chest/Back	6 (0)	9 (75)
Total anatomical area	107	56
Total patients	41	12
Average anatomical locations per patient	2.61	4.67

Percentage of casualties affected are indicated in parentheses.

Table 3 Diagnosis Classified Using ICD-9

Diagnosis	Survivors of IED	Killed in Action
Open wounds	41 (100)	12 (100)
Fractures	16 (39)	12 (100)
Burns	6 (15)	2 (16)
Amputations	3 (7)	6 (50)
Superficial injuries	4 (10)	2 (16)
Intracranial injuries	1 (2)	9 (75)
Hearing loss	6 (15)	NA
Blindness, visual disturbances	2 (5)	NA
Internal injury of thorax, abdomen, and pelvis	0 (0)	8 (67)
Total	79	51
Patients	41	12
Mean diagnosis per patient	1.92	4.25

Percentages of casualties affected are indicated in parentheses.
NA, not assayed.

the survivors group were uncommon and only seen in 6 of 41 (14.6%). All six casualties suffered minor fragmentation injuries to the chest and back, which did not penetrate the thoracic cavity.

In comparison, analysis of the postmortem data reveals a more extensive pattern of wounding, with a mean 4.67 body areas affected (range, 3–7). Significantly, torso injuries (10 of 12, 83.3%) and injuries to the head, neck, and face (9 of 12, 75%) were statistically greater in the fatalities group compared with the survivors group (Fisher's exact value two-tailed test $p < 0.05$).

The injuries sustained were categorized using the *The International Classification of Disease—9th edition* classification system and is shown in Table 3. Open wounds were present in all casualties and fractures were present in 28 (52.8%) of casualties. Ocular injuries were reported in two survivors; one had a minor corneal abrasion that was treated conservatively, the other sustained optic nerve injury in conjunction with severe head trauma. There was a statistically greater incidence of fractures, intracranial pathology, amputations, and penetrating injuries to the torso in the fatalities group compared with the survivors group (Fishers two-tail test $p < 0.05$).

All the IEDs were detonated a very short distance from the target vehicles. Despite the proximity of the blast only two casualties (3.7%), both of whom were fatalities, sustained significant blast injury to the lungs. A further six survivors were noted to have a perforated tympanic membrane; of these three were standing in the open turrets of the vehicles. Thermal injury was also uncommon and only seen in 8 (15.1%) casualties; six survivors and two fatalities. No casualty sustained burns greater than 5% body surface area.

The overall distribution of NISS scores is illustrated in Figure 1. It reveals a bimodal distribution of injury severity with casualties either sustaining relatively minor injuries or sustaining unsurvivable injuries. All of the fatalities had NISS scores of 75 (AIS 6, in at least one body region), which suggests that regardless of evacuation time or availability of medical resources these casualties would have died to their injuries.

The median NISS score of survivors was 3 (range, 1–50). We hypothesized that in incidents where there was a fatality, we would expect that the survivors in that vehicle would sustain more severe injuries. In incidents where there was no fatality, the mean NISS score of survivors (n = 28) was 4.39

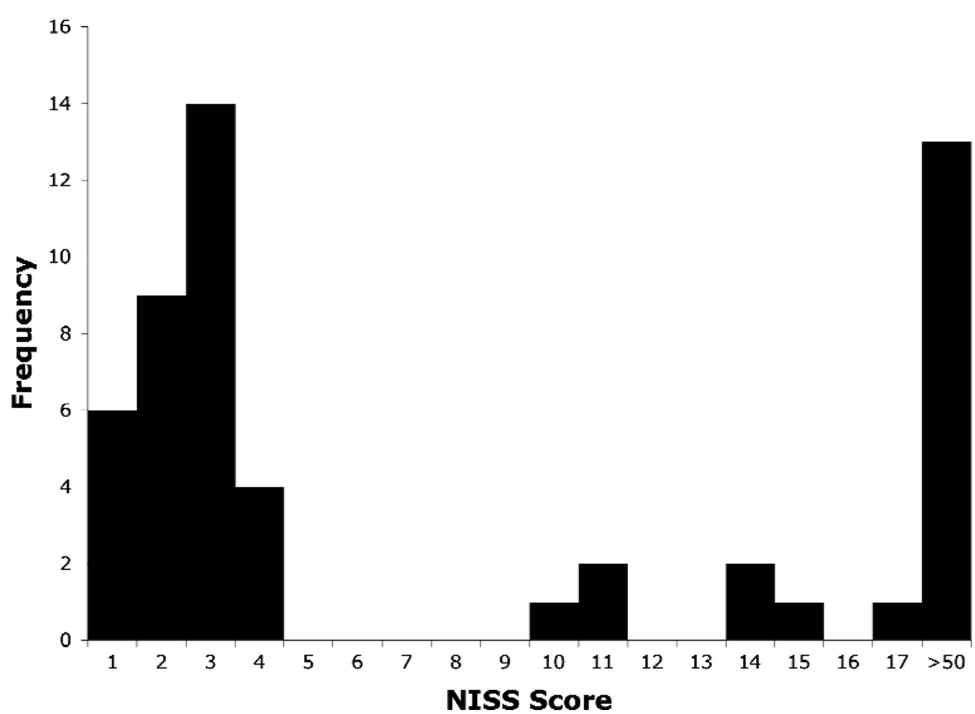

Fig. 1. *Distribution of NISS scores.*

(range, 1–17). However, in incidents where there was a fatality the mean NISS score of those survivors (n = 13) was 7.77 (range, 1–50). There was no statistical difference in the NISS scores between survivors of fatal and nonfatal incidents (two-tailed unpaired t test $p = 0.2301$).

Initial prehospital care was provided by medics on the ground, supplemented by a helicopter-borne immediate response team which includes a physician, nurse, and paramedics. Patients were treated in line with guidelines set out in the *Battlefield Advanced Trauma Life Support Manual*.[17] In two cases, the combat application tourniquet was applied for extremity wounds with life-threatening bleeding to gain initial control of hemorrhage. The combat application tourniquet has been validated in both laboratory trials and combat conditions.[18]

Twenty (48.7%) of the survivors required immediate surgical management in the field hospital. They underwent 30 procedures, which included wound debridéments (24), amputations (3), application of external fixators (2), and tracheostomies (1). In addition, one patient sustained significant closed head injuries after being thrown in a vehicle hit by an IED. He was transferred to a coalition neurosurgical unit for emergency surgery where he underwent a left frontotemperoparietal craniectomy with evacuation of subdural hematoma and a duraplasty with collagen matrix graft.

Casualties who sustained wounds less than 2 cm, not grossly contaminated and not involving underlying neurovascular structures, were treated conservatively with a 1-week course of oral Flucloxacillin and Penicillin V.[19,20] At 1 year, there were no wound complications after this treatment regimen.

After assessment and treatment at the field hospital, 19 were deemed fit to return back to duty in the theater of operations. Of the remaining 22 who were aeromedically evacuated out of Iraq, 18-month follow up was available on the 14 UK Service Personnel. All but one has since returned to full military duty.

DISCUSSION

Many studies published on military injuries are often retrospective due to the difficulties of collecting information reliably in austere and challenging clinical environments. By prospectively collecting data on both the injury mechanism and the injuries sustained, we were able to accurately profile the injuries from IEDs. To corroborate the initial incident reports from the attending prehospital medical team, we were also able to analyze the detailed incident reports produced by the weapon investigation teams. This allowed us to correlate the pattern of injury seen with the type of IEDs employed.

The Injury Severity Score has been the gold standard for anatomic severity scoring since its inception in 1974. The system is built on the AIS and sums the severity score of the three most severe injuries, but it only considers one injury per body region. The NISS modification was introduced by Osler in 1997 and sums the severity of the three most severe injuries irrespective of the body region. It has been suggested that the NISS is significantly better at predicting short-term mortality compared with the ISS.[21] The NISS score may be more appropriate in military trauma because many casualties sustain multiple injuries to the same body region and this would be better reflected using the NISS score compared with the ISS score. However, even the NISS score may not accurately reflect the severity of injury in casualties from explosions, as they often sustain multiple injuries bilaterally which can be underestimated using either the ISS or NISS scoring systems. These issues should be addressed if new injury scoring systems are to be developed to assess the pattern of injury seen in combat.

The anatomic pattern of wounding seen with IEDs bears similarity with data from the JTTR. Head and neck injuries were commonly affected in both our series and in the JTTR, with similar proportion of casualties sustaining these injuries.[8] The face remains relatively exposed and therefore, prone to injury. Previous analysis from the war in the Lebanon showed that the face was the most common body area injured in fatalities from that conflict.[22] As in all conflicts since World War I, extremity injuries are most commonly affected and the low incidence of torso injuries in survivors maybe attributed to the effectiveness of the enhanced combat body armour, which consists of a Kevlar and Nylon woven vest combined with large ceramic plates that cover a large proportion of the torso. Ocular injuries have been commonly associated with IED incidents, however they were not commonly seen in our series.[23] This may be in part due to the issue of ballistic eye protection to all combat troops operating in the region.

Our data would suggest that injuries from EFP-IEDs follow an "all or nothing " pattern; whereby casualties either died from catastrophic multiple injuries or sustained relatively minor injuries. Despite the close proximity of the vehicles to the explosion, significant primary blast injuries were uncommon and only seen in 3.7% of casualties. This would suggest that the blast component of these devices is not a significant factor in injury causation.

In open-air explosions, the initial overpressure of the blast wave is dissipated over a short distance. Previous studies have shown that mortality is related to the proximity of the victim to the device.[9] We therefore, hypothesized that fatalities from IEDs were more likely to be exposed to greater blast loading and consequently survivors from the same incidents would have more severe injuries compared with survivors from nonfatal incidents. However, there was no difference in the NISS scores of survivors in fatal and nonfatal incidents. This is contrasted by the data from Nelson et al.,[13] where survivors in fatal incidents were more severely injured than those involved in nonfatal incidents. On the basis of the previous experience, the injury patterns of different IEDs seem to be different.

We hypothesize that the injury pattern seen in our study is related to the use of the EFP-IED currently employed by

the insurgents in South Eastern Iraq. These are cylindrical charges, fabricated from commonly available metal pipe, with the forward end closed by a concave metal disc-shaped liner to create a shaped charge.[24,25] Explosive is loaded behind the metal liner to fill the pipe. When the explosive is detonated, the conical metal plate (or lens) is deformed and reshaped into an aerodynamically efficient penetrator moving at high velocity ($>$1,500 ms^{-1}). The EFP then hits the target at high speed, delivering significantly high mechanical energy.

We think that casualties caught in the trajectory of the EFP suffered catastrophic injuries whereas those sitting adjacent to the projectiles path suffered relatively less severe injuries. It would appear that the EFP-IED produces a more focused stream of fragments that cause injury to casualties caught in their path rather than the pattern of more dispersed fragmentation seen with conventional explosive devices. This would explain the wide variation of injury scores seen from casualties in the same vehicle compartment. In addition, the types of injuries encountered were predominantly secondary blast injuries related to being hit by the large metallic EFP or large fragments of the EFP.

As IEDs remain the leading cause of death among coalition troops, mechanisms to prevent the EFP from entering the passenger compartments may reduce the injuries causes by these devices. However, improvements in vehicle protection cannot fully prevent injuries from IEDs. The size of IEDs have also increased and in the past 12 months deaths have been reported in both UK armoured vehicles[26] and US mine-resistant armoured vehicles.[27]

CONCLUSIONS

We report a different pattern of injury caused by the EFP-IED compared with conventional explosive devices. Primary blast injury is not common in survivors but the EFP causes significant secondary blast injury to casualties caught in its path. Improvements in vehicle protection and improved tactics designed to detect these devices may help to reduce mortality and morbidity in troops operating in the region.

REFERENCES

1. Spalding TJ, Stewart MP, Tulloch DN, Stephens KM. Penetrating missile injuries in the Gulf war 1991. *Br J Surg.* 1991;78:1102–1104.
2. Hinsley DE, Rosell PA, Rowlands TK, Clasper JC. Penetrating missile injuries during asymmetric warfare in the 2003 Gulf conflict. *Br J Surg.* 2005;92:637–642.
3. Harnden T. Iraqis using ‘new Hizbollah bombs’ to kill British troops. Telegraph Group Limited, April 30, 2006. 2006. Available at: http://www.telegraph.co.uk/news/main.jhtml?xml=/news/2006/04/30/wiran130.xml. Accessed January 21, 2008.
4. Joint Tactics, Techniques and Procedures for Antiterrorism 3–07.2. Department of Defense, Joint publication; 1998.
5. Coalition wounded and deaths. 2008. Available at: http://icasualties.org/oif/default.aspx. Accessed 16 Jan 2008.
6. Owens BD, Kragh JF Jr, Macaitis J, Svoboda SJ, Wenke JC. Characterization of extremity wounds in Operation Iraqi freedom and operation enduring freedom. *J Orthop Trauma.* 2007;21:254–257.
7. Holcomb JB, McMullin NR, Pearse L, et al. Causes of death in U.S. Special Operations Forces in the global war on terrorism: 2001–2004. *Ann Surg.* 2007;245:986–991.
8. Owens BD, Kragh JF Jr, Wenke JC, Wade CE, Holcomb JB. Combat wounds in operation Iraqi Freedom and operation Enduring Freedom. *J Trauma.* 2008;64:295–299.
9. Mellor SG, Cooper GJ. Analysis of 828 servicemen killed or injured by explosion in Northern Ireland 1970–84: the Hostile Action Casualty System. *Br J Surg.* 1989;76:1006–1010.
10. Cooper GJ, Maynard RL, Cross NL, Hill JF. Casualties from terrorist bombings. *J Trauma.* 1983;23:955–967.
11. Leibovici D, Gofrit ON, Stein M, et al. Blast injuries: bus versus open-air bombings–a comparative study of injuries in survivors of open-air versus confined-space explosions. *J Trauma.* 1996; 41:1030–1035.
12. Arnold JL, Halpern P, Tsai MC, et al. Mass casualty terrorist bombings: a comparison of outcomes by bombing type. *Ann Emerg Med.* 2004;43:263–273.
13. Nelson TJ, Clark T, Stedje-Larsen ET, et al. Close Proximity Blast Injury Patterns From Improvised Explosive Devices in Iraq: A Report of 18 Cases. *J Trauma.* 2007; DOI: 10.1097/01.ta.0000196010.50246.9a.
14. Holcomb JB, Stansbury LG, Champion HR, Wade C, Bellamy RF. Understanding combat casualty care statistics. *J Trauma.* 2006; 60:397–401.
15. Osler T, Baker SP, Long W. A modification of the injury severity score that both improves accuracy and simplifies scoring. *J Trauma.* 1997;43:922–925; discussion 925–926.
16. 2006 International Classification of Disease. 9th Revision. Chicago, IL: American Hospital Association, 2006.
17. BATLS. *BATLS Manual*. Joint Service Publication 570. Crown Copyright; 2005.
18. Kragh JF Jr, Walters TJ, Baer DG, et al. Practical use of emergency tourniquets to stop bleeding in major limb trauma. *J Trauma.* 2008; 64:S38–S49; discussion S49–S50.
19. Bowyer GW. Management of small fragment wounds: experience from the Afghan border. *J Trauma.* 1996;40:S170–S172.
20. Bowyer GW, Cooper GJ, Rice P. Small fragment wounds: biophysics and pathophysiology. *J Trauma.* 1996;40:S159–S164.
21. Balogh Z, Offner PJ, Moore EE, Biffl WL. NISS predicts postinjury multiple organ failure better than the ISS. *J Trauma.* 2000;48:624–627; discussion 627–628.
22. Gofrit ON, Kovalski N, Leibovici D, Shemer J, O’Hana A, Shapira SC. Accurate anatomical location of war injuries: analysis of the Lebanon war fatal casualties and the proposition of new principles for the design of military personal armour system. *Injury.* 1996; 27:577–581.
23. Mader TH, Carroll RD, Slade CS, George RK, Ritchey JP, Neville SP. Ocular war injuries of the Iraqi Insurgency, January-September 2004. *Ophthalmology.* 2006;113:97–104.
24. Doig A. Some metallurgic aspects of shaped charged liners. *J Battlefield Technol.* 1998;1:1–8.
25. Morrison JJ, Mahoney PF, Hodgetts T. Shaped charges and explosively formed penetrators: background for clinicians. *J R Army Med Corps.* 2007;153:184–187.
26. Williams D. Iraqi bomb pierces our ‘invincible tank’. 2007. Available at: http://www.mailonsunday.co.uk/pages/live/articles/news/news.html?in_article_id=450189&in_page_id=1770. Accessed 24 April 2008, 2008.
27. Vanden Brook T. First U.S. soldier in Iraq dies in new mine-resistant vehicle. 2008. Available at: http://www.usatoday.com/news/military/2008-01-22-iraq-mrap_N.htm. Accessed 24 April 2008, 2008.